



Nickel oxide hollow microsphere for non-enzyme glucose detection

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ABSTRACT

A facile strategy has been developed to fabricate nickel oxide hollow microspheres (NiO-HMSs) through a solvothermal method by using a mixed solvent of ethanol and water with the assistance of sodium dodecyl sulfate (SDS). Various techniques, including transmission electron microscopy (TEM), scanning electron microscopy (SEM), and powder X-ray diffraction (XRD), were used to characterize the morphology and the structure of as-prepared samples. It was confirmed that the products possess a hollow microsphere structure that is constructed by interconnecting porous nanoplate framework. Electrochemical studies indicate that the NiO-HMS exhibits excellent stability and high catalytic activity for electrocatalytic oxidation of glucose in alkaline solutions, which enables the NiO-HMS to be used in enzyme-free amperometric sensors for glucose determination. It was demonstrated that the NiO-HMS-based glucose biosensor offers a variety of merits, such as a wide linear response window for glucose concentrations of 1.67 μM –6.87 mM, short response time (3 s), a lower detection limit of 0.53 μM ($S/N=3$), high sensitivity ($\sim 2.39 \text{ mA mM}^{-1} \text{ cm}^{-2}$) as well as good stability and repeatability.

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1. Introduction

Development of glucose sensors is of great importance in a variety of fields, including medical applications of blood glucose testing, environmental monitoring, pharmaceutical analysis, and process control in food and textile industries. In the past decades, tremendous effort has been devoted to exploring reliable glucose sensor technique aiming to realize in vitro or in vivo glucose measurements and to achieve rapid response, high sensitivity, excellent selectivity, and low cost. A few potential glucose sensing approaches have been developed for measuring glucose concentrations based on fluorescent, optical, acoustic, transdermal, surface plasmon resonance, electro-chemiluminescence, and electrochemical signals (Chen et al., 2013; Heller and Feldman, 2008; Ronkainen et al., 2010; Scognamiglio, 2013; Wang, 2008). Among these techniques, the electrochemical sensor has been recognized as one of the most convenient and promising approaches due to its numerous merits, such as simplicity, high sensitivity, low production cost, attractive lower detection limit, and compatibility for miniaturization (Chen et al., 2013; Wang et al., 2007, 2008; Heller and Feldman, 2008). Electrochemical detection of glucose is usually based on the glucose oxidase (GOD)

enzymatic reaction, in which glucose reacts with oxygen to produce gluconolactone and hydrogen peroxide (H_2O_2) with the catalyzing assistance of GOD. Therefore, the glucose level can be indirectly measured through electrochemical determination of the consumption of dissolved oxygen or the production of H_2O_2 . The drawback of this approach is that the activity of GOD is extremely sensitive to the environmental conditions (e.g., temperature, pH, etc.) and highly dependent on the enzyme immobilization techniques, leading to insufficient long-term stability and unsatisfactory reproducibility (Sasso et al., 1990; Liu et al., 2007; Li et al., 2010a; Wilson and Turner, 1992). To address these issues, enormous effort has been devoted to exploring non-enzyme glucose biosensors in recent years. It is therefore highly desirable to develop efficient electrocatalysts for electrochemical reaction of glucose (Jiang and Zhang, 2010; Park et al., 2006).

Recent advancements in this field have suggested that a variety of transition metals and transition metal oxides (e.g., Au, Pd, Pt, Cu, Ni, CuO, NiO, CoO, MnO_2 , etc.) could work as electrocatalysts for glucose oxidation reactions in alkaline electrolytes, which makes it possible for non-enzymatic determination of glucose (Cao et al., 2013; Chen et al., 2013, 2008; Jiang and Zhang, 2010; Kang et al., 2007; Li et al., 2010a, 2010b; Liu et al., 2009; Moussy et al., 1994; Rong et al., 2007; Salimi and Roushani, 2005; Song et al., 2005; Wang, 2008; Wang et al., 2008; Yang et al., 2010; Zhai et al., 2013; Zhu et al., 2013). Ni-based materials have been extensively investigated as electrode materials for constructing non-enzyme biosensors because they can function as efficient catalysts for the

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electrocatalytic oxidation of glucose resulting from the redox couple of $\text{Ni}^{3+}/\text{Ni}^{2+}$ in the alkaline medium (Danaee et al., 2012, 2008; Ding et al., 2011b; Jiang and Zhang, 2010; Liu et al., 2009; Lu et al., 2009; Luo et al., 2013; Tian et al., 2013). So far, most Ni-based non-enzymatic glucose sensors are constructed by modifying substrates with nickel-based nanoparticles, nickel/carbon hybrids, or porous nickel nanomaterials. Hollow structures should deserve more attention for design and fabrication of biosensors with improved performance. However, it still remains a great challenge to fabricate NiO hollow structures especially without the assistance of hard templates (Lou et al., 2008). Furthermore, there are few reports on Ni-based hollow structures for glucose biosensor applications, despite the fact that the hollow structure and corresponding properties, such as well-defined interior voids, high specific surface area, low density, and structural stability, may bring about various advantages such as high sensitivity, good stability, and low detection limit.

We herein demonstrate a non-enzymatic electrochemical sensor for glucose determination based on NiO nanoplate-constructing hollow microsphere (NiO-HMS)-modified electrodes. Such a porous hollow microsphere structure offers a suitable structure and a large surface area, facilitating electrolyte or ion transport at the solid/liquid interface and allowing the active materials to easily access glucose molecules. It was demonstrated that the NiO-HMSs are constructed by an interconnecting nanoplate framework and show desirable performance with excellent repeatability and long-term stability for non-enzymatic biosensor applications.

2. Experimental

2.1. Materials and synthesis

All chemicals were used as received from Sigma-Aldrich without treatment. NiO-HMSs were synthesized using a solvothermal method. In a typical experiment, 0.1 g of sodium dodecyl sulfate (SDS) was dissolved in 30 ml ethanol and 30 ml water at room temperature. 5.0 mM urea and 5.0 mM nickel chloride (NiCl_2) were then added into the solution with vigorous agitation. The mixed solution was then transferred to a 100 ml Teflon-lined stainless steel autoclave and heated at 160 °C for 10 h. After completely cooling down, the products were filtered and then washed for three times with distilled water and absolute alcohol, respectively. The green powders after drying were calcined at 500 °C for 2 h to convert to NiO. Bulk NiO was prepared by stoichiometrically mixing NiCl_2 with KOH, followed by annealing the green precipitate at 500 °C for 2 h.

2.2. Characterization

The structure and the morphology of the samples were characterized using a LEO 1530 scanning electron microscope (SEM) and a Hitachi model H-800 transmission electron microscope (TEM). Power X-ray diffraction (XRD) was conducted on a Scintag XDS 2000 X-Ray Diffractometer. Specific surface areas, pore volume and pore size distributions were tested at 77 K through Brunauer–Emmett–Teller (BET) nitrogen adsorption-desorption (Shimadzu, Micromeritics, ASAP 2010 Instrument).

2.3. Electrochemical testing

The modified electrode was prepared as follows: the glass-carbon electrode (GCE) was polished with alumina slurry, and then ultrasonically cleaned alternately in ethanol and double-distilled water. The NiO-HMSs (5 mg) were dissolved in a mixture of 0.05 mL

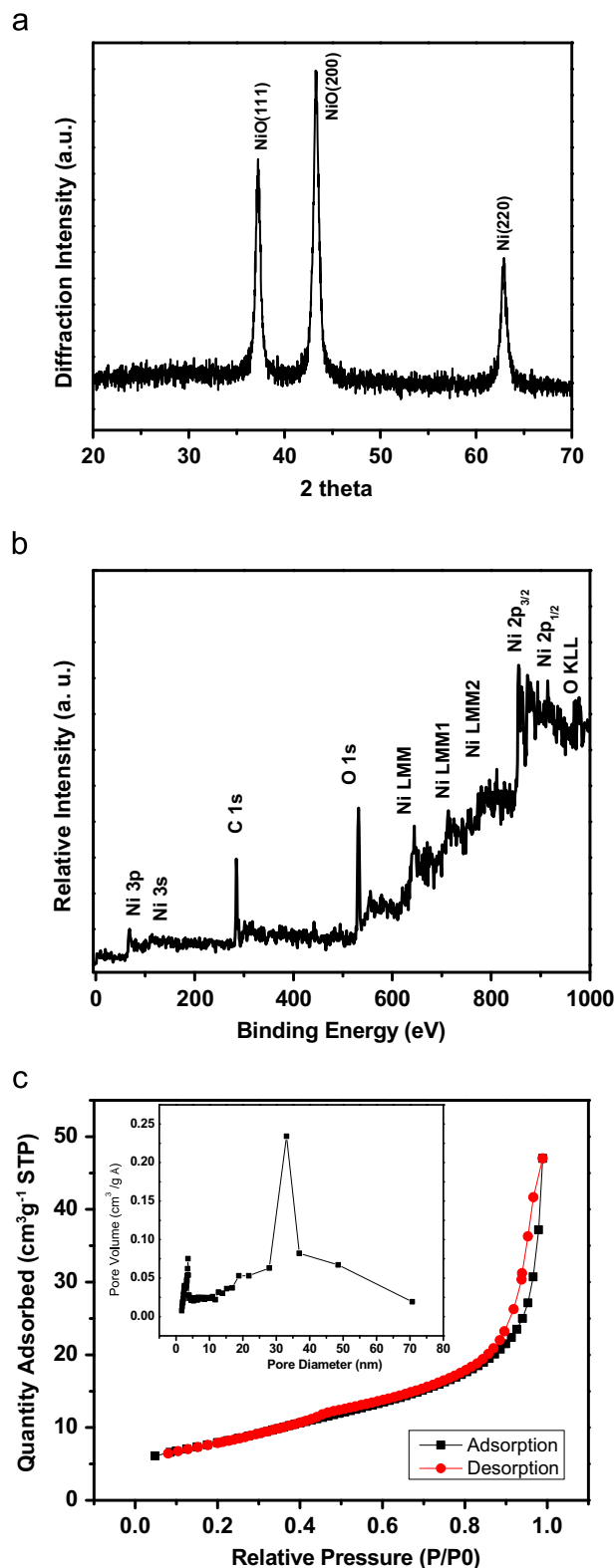


Fig. 1. (a) XRD pattern, (b) XPS spectrum, and (c) Nitrogen adsorption/desorption isotherms of the NiO-HMS.

Nafion and 0.45 mL distilled water. A suspension was obtained under ultrasonic agitation for a few minutes. Then 6 μL of the mixture was dropped onto the cleaned GCE and allowed to dry at room temperature. All electrochemical measurements were carried out on a Model CHI 760D Electrochemical Workstation (CH Instruments, USA) using a conventional three-electrode system fitted

with a magnetic stirrer. All solutions were deoxygenated with highly pure argon (99.9%) for at least 15 min before measurements. All potentials reported here were referred to the KCl saturated Ag/AgCl electrode (+0.194 V vs. standard hydrogen electrode). The geometric surface area of the modified electrode (0.071 cm^2) was used to calculate current densities. The glucose concentration in the blood serum, which was drawn from blood to clot with assistance of centrifugation, was determined using the NiO-HMSs electrode, and the current response was measured by adding a given amount of blood serum into electrolyte. In addition, a Breeze blood glucose monitoring system (Bayer HealthCare LLC, Mishawaka, USA) was used to verify the detection results through an *F*-test.

3. Results and discussion

3.1. Characterization

Fig. 1a shows the X-ray diffraction (XRD) patterns of the as-prepared products. The diffraction peaks at $2\theta = 37.2^\circ$, 43.2° , and 62.6° are consistent with the (1 1 1), (2 0 0), (2 2 0) planes of the cubic structure of NiO (JCPDS No. 47-1049). No impurity-phase peak was found, demonstrating the products are pure phase NiO. X-ray photoelectron spectroscopy (XPS) was also carried out to investigate the chemical states of bonded elements in the as-prepared samples. As shown in Fig. 1b, the survey XPS spectra display a set of peaks corresponding with C1s, O1s, and Ni2p spectra, respectively. It should be noted that C1s (285.1 eV) is ascribed to a carbon-based substrate, while the peak at $\sim 531.6 \text{ eV}$

and $\sim 855.7 \text{ eV}$ are attributed to O1s and Ni2p spectra, respectively. We also investigated the surface area and the porous structure based on the Brunauer–Emmett–Teller (BET) method. Fig. 1c shows the nitrogen adsorption-desorption isotherm curves measured at 77 K, which exhibits a distinct hysteresis loop at a relative pressure P/P_0 ranging from 0.4 to 0.8 (inset of Fig. 3b), corresponding with the IV isotherm curves and indicating the existence of mesopores according to the IUPAC nomenclature. The as-prepared NiO samples possess a BET surface area of $28.4 \text{ m}^2/\text{g}$, a pore volume of $0.07 \text{ cm}^3/\text{g}$, and an average pore size of $\sim 9.4 \text{ nm}$.

SEM and TEM were performed to characterize the structure and the morphology of the as-synthesized samples. Fig. 2a shows a representative SEM image, from which one can observe a well-defined microsphere with a size range of 5–10 μm . Fig. 2b is an SEM image of a broken microsphere, demonstrating the samples are actually hollow microspheres with a shell thickness of $\sim 500 \text{ nm}$ and a large void of $\sim 9 \mu\text{m}$. Interestingly, it was revealed that, according to a magnified SEM image (Fig. 2c), the shell of the hollow microsphere is constructed of a large number of porous NiO nanoplates. The NiO-HMS was further characterized by taking elemental mapping images of nickel and oxygen to analyze the element distribution (Fig. 2d–f), which reconfirms the structure being a hollow microsphere with a uniform distribution of Ni and O.

Fig. 2g shows a typical TEM image of NiO-HMSs; one can clearly observe lots of pores on the microsphere and a blurry void with a diameter of 1 μm in the center, which is much smaller than that observed by SEM, possibly because the shell is too thick to be penetrated by the electron beam. Fig. 2h displays selected area electron diffraction (SAED) patterns of NiO-HMSs. Consistent with

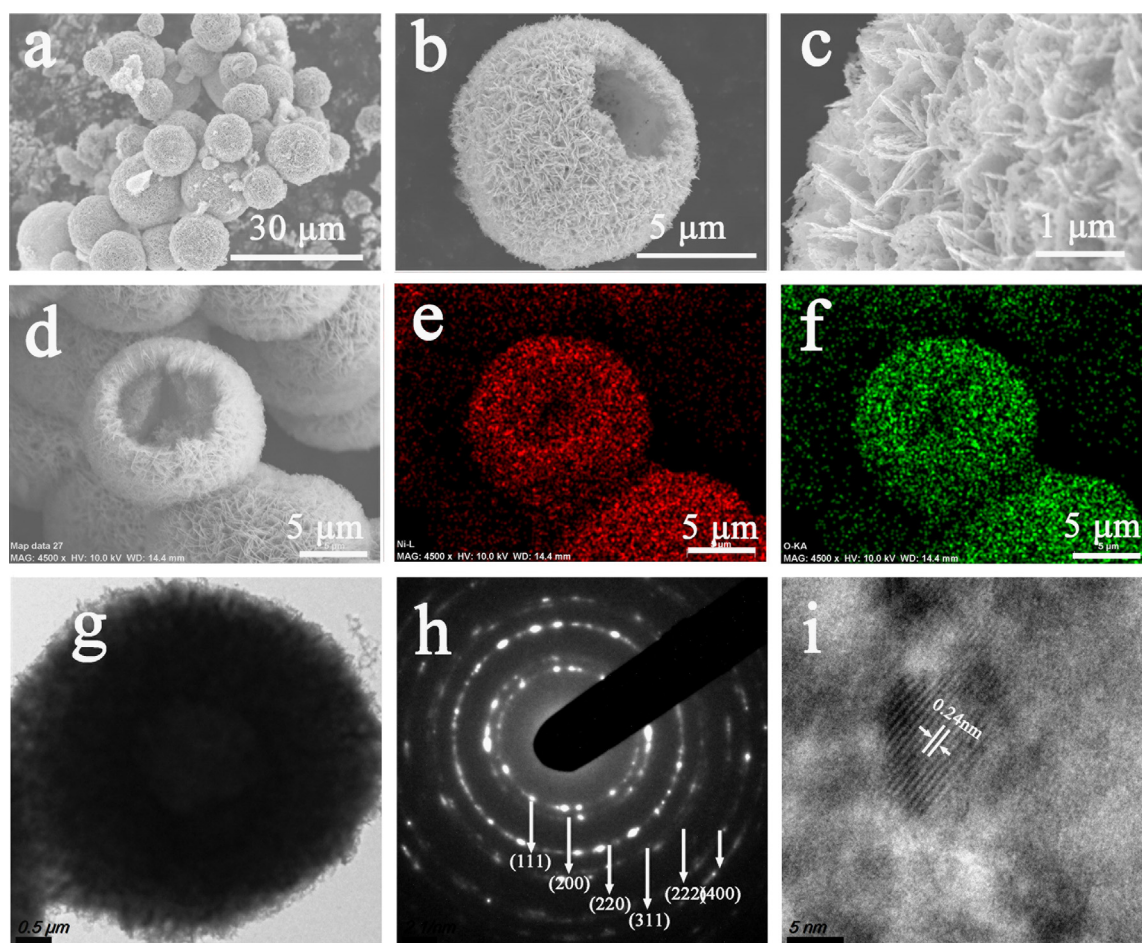


Fig. 2. ((a)–(c)) SEM images of NiO-HMSs with different magnifications; and electron energy loss spectroscopy mapping images of the NiO-HMS: (d) zero-energy loss bright field image, (e) nickel elemental mapping, (f) oxygen elemental mapping; (g) TEM, (h) SAED pattern, and (i) HRTEM image of the NiO-HMS.

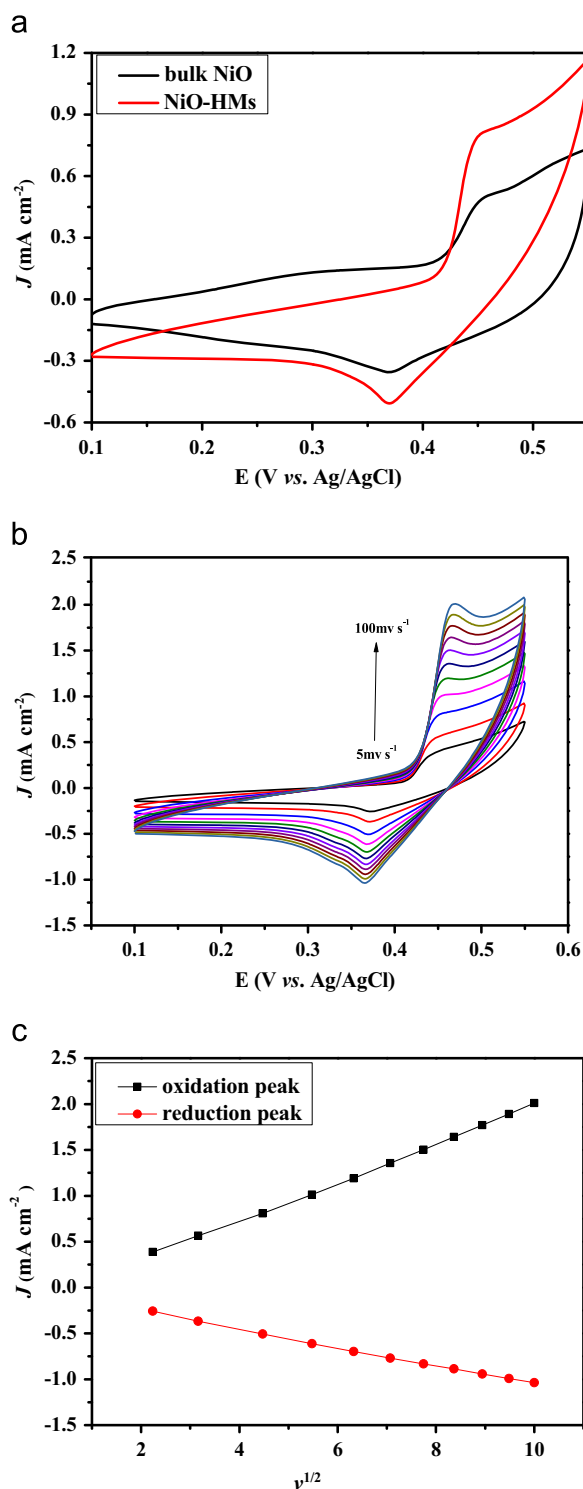


Fig. 3. (a) CVs of the bulk-NiO/GCE and the NiO-HMS/GCE in 0.1 M NaOH at a scan rate of 20 mV s⁻¹. (b) CVs of the NiO-HMS/GCE in 0.1 M NaOH at different scan rates (5–100 mV s⁻¹). (c) Relationship between j_p and $\nu^{1/2}$ for CVs of the NiO-HMS/GCE in 0.1 M NaOH.

XRD results, several well-defined rings corresponding with diffraction planes of NiO can be found, suggesting that the NiO-HMSs have a good crystalline structure. According to the high-resolution TEM image (Fig. 2i), the building blocks of hollow microspheres, i.e., nanoplates, actually consist of numerous NiO nanocrystals with a well-defined lattice spacing of 0.24 nm corresponding with the (1 1 1) lattice plane of NiO.

3.2. Electrochemical behavior of the NiO-HMS electrode

Fig. 3a represents the cyclic voltammograms (CVs) of the bulk-NiO modified glass carbon electrode (bulk-NiO/GCE) and the NiO-HMS modified glass carbon electrode (NiO-HMS/GCE) in 0.1 M Ar-saturated NaOH solution at a scan rate of 20 mV s⁻¹. Both bulk-NiO and NiO-HMS display a pair of well-defined redox peaks with anodic peak and cathodic peak at +0.45 V and +0.37 V, respectively. Apparently, the NiO-HMS shows much higher electrochemical activity than the bulk NiO electrode, as is evidenced by a higher peak current response (i_p) and a smaller peak potential separation (ΔE_p) of 80 mV at the NiO-HMS electrode. It should be noted that the couple of peaks are attributed to the redox reaction of Ni²⁺/Ni³⁺ couple on the electrode surface in the alkaline medium (Mu et al., 2011; Nie et al., 2011; Niu et al., 2013):



Fig. 3b shows the CVs of the NiO-HMS/GCE at various scan rates (5–100 mV s⁻¹). The anodic peak shows a slight positive shift while the cathodic peak moves negatively with the increase in scan rate, indicating a quasi-reversible electron transfer reaction for the above electrochemical reaction. Moreover, the peak current densities for both the oxidation and the reduction are proportional to the square root of the scan rate, as depicted in Fig. 3c, implying that the electrochemical reaction on the surface of the NiO-HMS/GCE is a diffusion-controlled process.

3.3. Electrocatalytic oxidation of glucose

The CV technique was further used to investigate the electrochemical behavior of the NiO-HMS/GCE in 0.1 M NaOH without and with the presence of glucose. After adding glucose into the electrolyte, the anodic peak current shows a remarkable enhancement accompanying with a slight positive shift of peak potential, and an apparent abatement of the cathodic peak (Fig. 4a), suggesting excellent electrocatalytic activity of NiO-HMS on glucose oxidation. The oxidation of glucose to glucolactone was electrocatalyzed by the NiOOH/NiO redox couple according to the following electrochemical reaction (Mu et al., 2011; Ni et al., 2010; Zhang et al., 2011; Zhu et al., 2011):



The increase of anodic current is attributed to the electro-oxidation of glucose with NiO-HMS as an electrocatalyst, which is accompanied with the oxidation of Ni²⁺ to Ni³⁺. Because the electro-oxidation of glucose consumes Ni³⁺, which in turn results in the slight decrease of cathodic peak current. On the other hand, the addition and oxidation of glucose would inevitably induce adsorption of glucose and the oxidized intermediates on active sites of Ni-based materials, which may slow down the kinetics of the corresponding reaction and thus give rise to a slight positive shift in the anodic peak (Zheng et al., 2009). In contrast, the bulk-NiO/GCE exhibits a negligible catalytic effect on glucose oxidation, as revealed in Fig. 4b, which shows the CV responses in the absence and the presence of glucose. Fig. 4c displays double-step chronoamperograms of the NiO-HMS/GCE over a concentration range of 0.1–0.8 mM glucose with an applied potential step of 0.50 V and 0.35 V, respectively. The net current presents a linear dependency on the inverse square root of time in 0.1 mM glucose (Fig. 4d). Based on the Cottrell equation, $i = nFAD^{1/2}c_0(\pi t)^{-1/2}$, the diffusion coefficient of glucose was calculated as $1.53 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$ using the slope of this line, which is in good agreement with the value reported in previous reports (Danaee et al., 2012; Torto et al., 1999). The current values of different glucose concentrations are negligible when the potential is stepped down to 0.35 V, further indicating the irreversibility of the glucose oxidation process (Bedden et al., 1996).

3.4. Amperometric detection of glucose

It is well known that the applied potential significantly affects the amperometric response of an electrochemical biosensor. Therefore, constant potential chronoamperometry was performed by varying the potential around the anodic peak potential to investigate the current response with successive addition of 0.1 mM glucose under stirred condition; in this way, a suitable potential can be optimized for glucose detection. As shown in Fig. 5a, when a potential below 0.50 V (e.g. 0.40 V and 0.45 V) was applied, a small current response was observed with each addition of glucose. However, an applied potential of 0.50 or 0.55 V led to a remarkable enhancement in the current response upon each addition of glucose. Because of the relatively low potential of glucose detection, it is of great benefit to lower the background current and noise. Given the fact that gases will be produced on the surface of the electrode at a high potential, a potential of 0.50 V was selected as the optimum working potential for amperometric detection of glucose in the subsequent studies. To verify the enhanced performance of the NiO-HMS, the same procedure was carried out for the bulk-NiO/GCE at the optimized detection potential of 0.50 V. As expected, the bulk-NiO/GCE only shows a slight current response for each addition of glucose (Fig. 5b), which is consistent with the behavior observed in the CV results. Actually, the NiO-HMS/GCE shows a current response of $85.6 \pm 0.4 \mu\text{A}$ upon addition of 0.1 mM glucose, which is more than 5 times that of the bulk-NiO/GCE ($16.9 \pm 0.02 \mu\text{A}$). All above results indicate the NiO-HMS possesses excellent catalytic performance for glucose oxidation and thus is promising for constructing a highly sensitive glucose biosensor.

The amperometric response of the NiO-HMS/GCE to the successive step-wise addition of glucose was carried out at an applied potential of 0.50 V. As shown in Fig. 5c, the sensor produces a

rapid (achieving 95% of the steady-state current in less than 3 s) and sensitive response to the addition of glucose. The corresponding calibration plot presented in inset of Fig. 5d is linear over a concentration range of $1.67 \mu\text{M}$ – 0.42 mM glucose with a slope of $167.37 \mu\text{A mM}^{-1}$ and a correlation coefficient of 0.995. The sensitivity of the NiO-HMS sensor is calculated as $2.39 \text{ mA mM}^{-1} \text{ cm}^{-2}$ by dividing the slope of the linear regression equation by the electrode surface area. It should be noted that when the concentration of glucose continuously increased to a threshold, the current response decreased accordingly and the calibration curve tended to level off at a glucose concentration higher than 5 mM. Such an electrochemical response is similar to typical Michaelis-Menten kinetic characteristic of an enzyme-based electrode (Kumar and Zen, 2001), indicating all active sites of NiO-based materials are bound to the glucose substrate at higher glucose concentrations. Based on a signal-to-noise ratio of 3 (S/N), a lower detection limit of $0.53 \mu\text{M}$ can be obtained. The obtained sensitivity of the NiO-HMS/GCE sensor is higher than various non-enzyme glucose sensors reported previously, such as NiO-Au hybrid nanobelts/GCE (Ding et al., 2011a), NiO-Pt hybrid nanofibers/GCE (Ding et al., 2011b), Ni(OH) nanoboxes/GCE (Nai et al., 2013), Pt/Ni-Co nanowires electrode (Mahshid et al., 2013), nano NiO electrode (Mu et al., 2011), NiNPs/SMWNTs electrode (Nie et al., 2011), Ni nanowire-modified electrode (Wang et al., 2012a), Ni nanospheres/reduced graphene oxide hybrids electrode (Wang et al., 2012b) and RGO-Ni(OH)₂/GCE (Zhang et al., 2011), comparable to that of a highly sensitive three-dimensional porous nickel electrode (Niu et al., 2013). Additionally, the detection limit of the NiO-HMS sensor is lower than those of other nickel-based non-enzymatic sensors (Ding et al., 2011a; Lu et al., 2013; Mahshid et al., 2013; Wang et al., 2012a, 2012b). The high sensitivity and low detection limit can be attributed to the hollow structure of the NiO-HMS, which provides a high specific

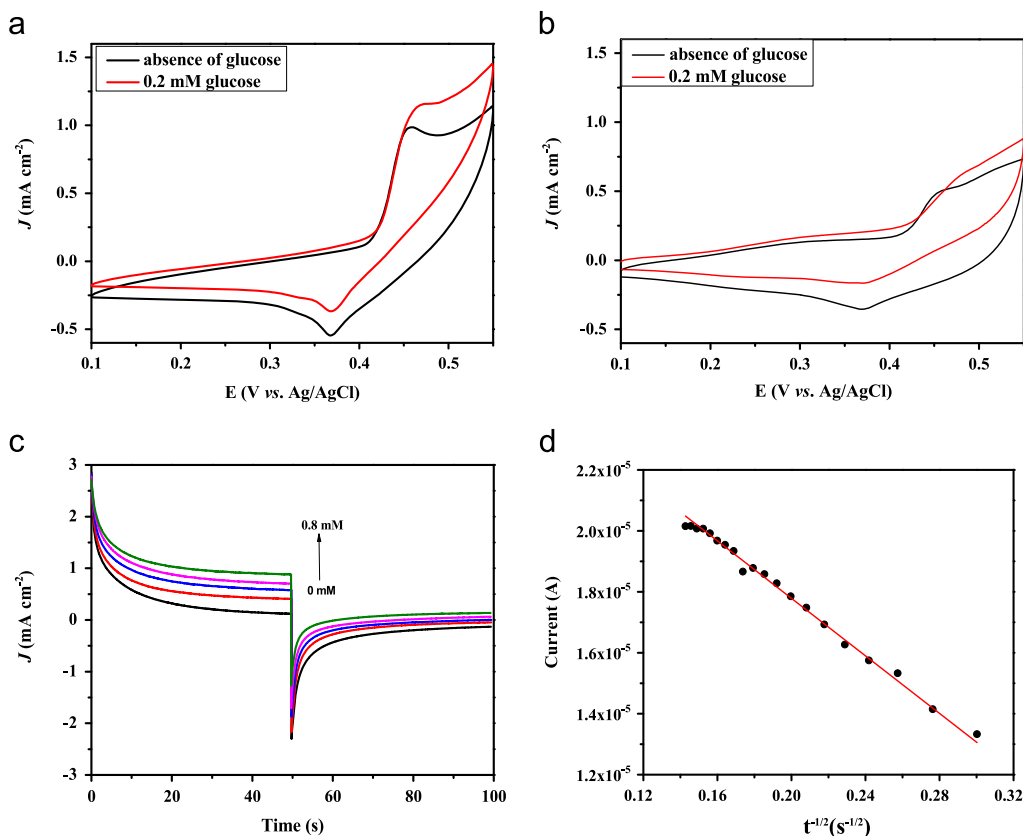


Fig. 4. CVs of the NiO-HMS/GCE (a) and the bulk-NiO/GCE (b) in 0.1 M NaOH in the absence and presence of glucose. (c) Double chronoamperograms of the NiO-HMS/GCE in 0.1 M NaOH solution with different concentrations of glucose and applied potential steps of 0.50 and 0.35 V. (d) Dependency of transient current on $t^{-1/2}$ derived from the data of chronoamperograms of (a) and (b) in Fig. 2c.

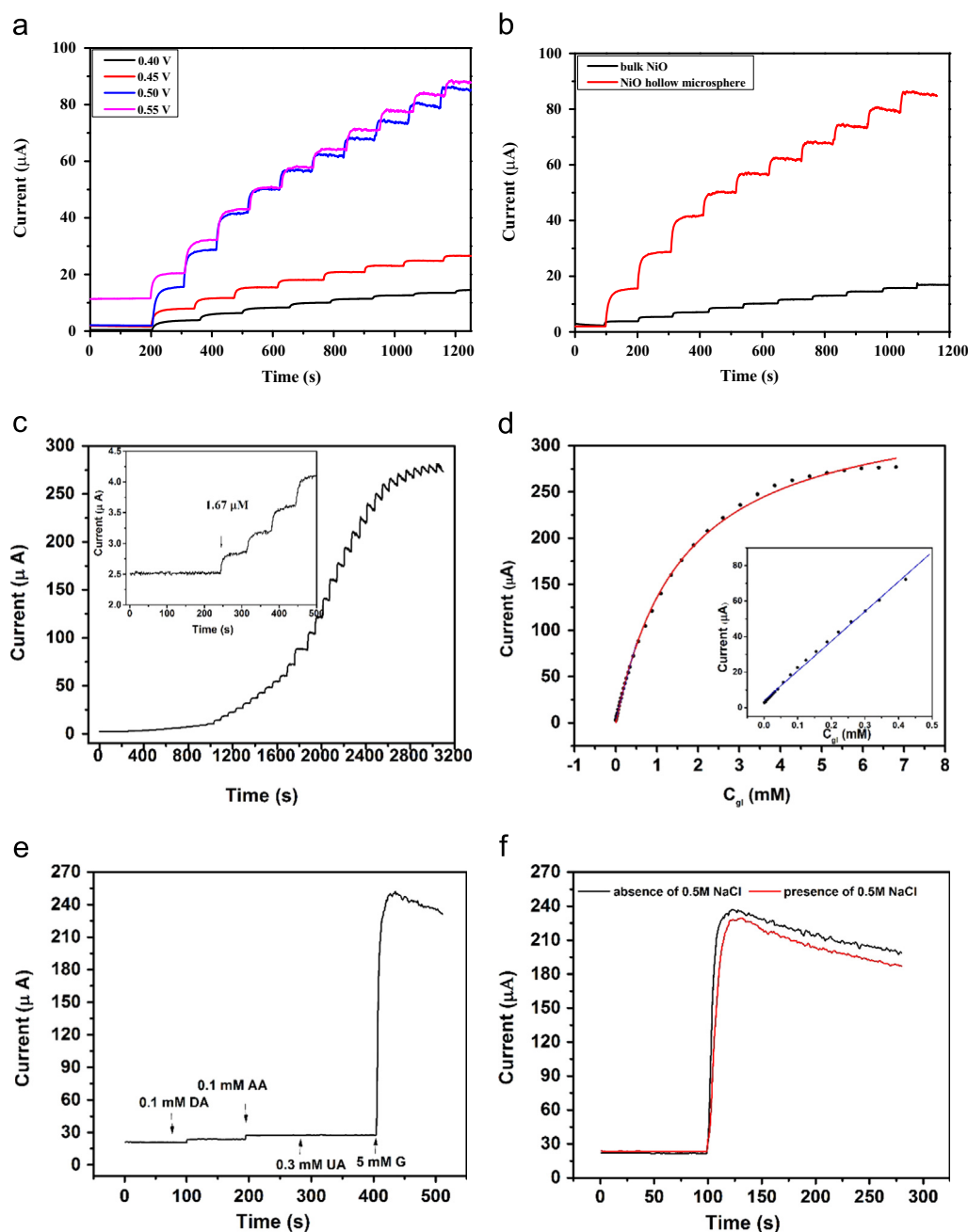


Fig. 5. (a) Amperometric response of the NiO-HMS/GCE at different potentials with successive addition of 0.1 mM glucose into 0.1 M NaOH solution; (b) Amperometric response of the bulk-NiO/GCE and the hollow NiO/GCE with the successive addition of 0.1 mM glucose at 0.50 V; (c) Amperometric response of the NiO-HMS/GCE to successive addition of glucose at 0.5 V; inset: amperometric response to 1.67 μ M glucose; (d) Calibration curve for current density vs. concentration of glucose; inset is the corresponding linear relation in the range of 1.67 μ M–0.42 mM; (e) Amperometric response of the NiO-HMS to successive addition of 0.1 mM DA, 0.1 mM AA, 0.3 mM UA and 5 mM glucose at an applied potential of 0.50 V; (f) Amperometric response of the NiO-HMS/GCE to the addition of 5 mM glucose without and with 0.5 M NaCl in 0.1 M NaOH solution.

surface area and numerous active sites and also allows the access of analytes to all active catalytic sites with minimal diffusion resistance.

Since the electrochemical oxidation of glucose on the electrode is a surface catalytic reaction (Ding et al., 2010; Lang et al., 2013; Zhang et al., 2012, 2014), the Langmuir fitting equation, which was derived based on Langmuir isothermal theory, i.e., $I = a \times C_{\text{glucose}} / (b + C_{\text{glucose}})$, is used to fit the calibration curve. As shown in Fig. 5d, the corresponding Langmuir fitting equation ($R^2 = 0.999$) for the glucose sensor NiO-HMS is presented as I (μ A) = $353.99 \times C_{\text{glucose}}$ (mM) / $(1.61 + C_{\text{glucose}}$ (mM)), which can cover a broad range (1.67 μ M–6.87 mM) required for glucose detection in real samples. When glucose concentration is low (≤ 0.4 mM), the equation can be approximated as $I = 176.99 \times C_{\text{glucose}}$. Thus the

sensitivity is calculated as $2.52 \text{ mA mM}^{-1} \text{ cm}^{-2}$, which is in good agreement with the previous result ($2.39 \text{ mA mM}^{-1} \text{ cm}^{-2}$) if only the linear range is considered.

3.5. Interference study and long-term stability

Selectivity is one of the vital characteristics of high-performance non-enzymatic glucose sensors. In the sample analysis, co-existence of other electroactive species, such as ascorbic acid (AA), uric acid (UA), and dopamine (DA), might affect the detection of glucose (Ni et al., 2010). Therefore, the effects of interfering species (e.g., DA, AA, and UA) on the NiO-HMS/GCE sensor were investigated at a physiological concentration. As shown in Fig. 5e, the corresponding

oxidation current change is $214.33 \pm 5.54 \mu\text{A}$ upon adding 5 mM glucose, which greatly exceeds those recorded for the interfering species, i.e., $3.80 \pm 0.08 \mu\text{A}$ for DA (0.1 M) and $4.38 \pm 0.15 \mu\text{A}$ for AA (0.1 M), and almost no current response for UA (Niu et al., 2013). Therefore, the presence of AA, DA, and UA does not interfere with the detection of glucose. In addition, sensing selectivity of the NiO-HMS/GCE sensor towards glucose oxidation in the presence of chloride ions has been tested using an amperometric method (Fig. 5f). It can be seen that the injection of 5 mM glucose into a solution with a high chloride ion concentration (0.1 M NaOH + 0.5 M NaCl) showed only a very slight current change (less than 5%) compared with the current response to glucose without chloride ions.

The long-term stability of the NiO-HMS sensor was investigated by recording the current response to 0.5 mM glucose in 0.1 M NaOH. The current response of every test remained above 93% of the initial response current for ten days. The relative standard deviation (RSD) of the response currents was 5.2%, which suggests that the modified electrode possesses good stability. Four NiO-HMS/GCEs, prepared independently, yielded an acceptable RSD of 3.7% for the current determination in the presence of 0.5 mM glucose. Such good stability and repeatability make the NiO-HMS/GCE sensors attractive for practical applications. The NiO-HMS sensor was further applied to the detection of the glucose level in human blood. Five serum samples were prepared by drawing blood to clot at 37 °C with assistance of centrifugation. The glucose content in blood serum was determined using the present electrochemical method and the Breeze blood glucose monitoring system, respectively. *F*-test was carried out to assess the validity of glucose detection between the NiO-HMS/GCE sensor and the commercial glucose. The calculated *P* value was 0.03 ($P < 0.05$); therefore, the standard deviations between these two methods are statistically different, suggesting 95% confidence of our method.

4. Conclusion

In summary, a facile method has been developed to fabricate NiO hollow microspheres (NiO-HMSs) with porous nanoplates as a building block. The as-prepared NiO-HMS was successfully applied for electrode modification in the fabrication of a glucose sensor, which exhibited advantages of high sensitivity, fast response, and excellent stability for non-enzymatic determination of glucose levels. The simple preparation procedure, low cost, and enhanced electrocatalytic performance can potentially pave the way for inexpensive, effective, and highly sensitive glucose sensors.

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